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Subsidence at the Weeks Island SPR Facility

Stephen J. Bauer
Underground Storage Technology Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0706

Abstract

The elevation change data measured at the Weeks Island SPR site over the last 16+ years has been studied and analyzed. The subsidence rate is not constant with time and while the subsidence rate may have increased slightly during the past several years, recently the rate has increased more dramatically. The most recent increase comes at a time when the Strategic Petroleum Reserve (SPR) storage mine had been emptied of oil and was in the process of being refilled with brine. Damage to surface structures that has been observed during the past 12-18 months is attributed to the continued subsidence and differential subsidence across structures. The recent greater subsidence rates were unanticipated according to analysis results and will be used to aid further subsidence model development.

Acknowledgements

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Introduction

The Weeks Island salt dome is located 23 km (14 mi) south of New Iberia, Louisiana, and is the central dome in the Five Islands chain, along with Belle Isle, Cote Blanche, Avery, and Jefferson Islands. All five have been mined because of their near-surface salt, and their logistical advantage near the Gulf of Mexico and the Intracoastal Waterway. Belle Isle and Jefferson Island are now closed to mining because of deliberate and inadvertent flooding, respectively.

The sediment cover at Weeks Island consists of deltaic alluvium of the ancestral Mississippi River and is about 56 m (185 ft) thick over the top of salt. The water table conforms generally to sea level over the dome but fluctuates somewhat with topography and frequent torrential rains.

The Weeks Island Strategic Petroleum Reserve (SPR) facility is a former conventional two level room and pillar mine (Figure 1) purchased by the Department of Energy (DOE) from Morton Salt for the purpose of storing SPR oil. The mine was originally opened in 1902 and salt was extracted commercially until 1977, at which time Morton Salt developed a new mine immediately adjacent to the northwest while the older workings were converted for oil storage. The mine contained approximately 73 million barrels of crude oil from 1981 to 1996, at which time the removal of oil began.

Although not the subject of this report, products of local subsidence over the mine are sinkholes. A sinkhole measuring 11 m (36 ft) across and 9 m (30 ft) deep was first observed in the alluvium overlying the salt dome in May 1992. Based on initial surface appearance and subsequent reverse extrapolation of growth rates, it was already about a year old at discovery. A second and much smaller sinkhole was identified in early 1995, nearly three years later. Their positions are located directly over the edges of the SPR oil storage chamber. The association of sinkholes with mines is well established. However, this occurrence suggested that groundwater influx into the mine was causing salt dissolution at depth, with associated collapse of soil at the surface (Neal, et al., 1998).

Beginning in January 1983, the subsidence monument elevations at the Weeks Island site have been surveyed 15 times. Bauer and Neal (1997) have most recently reported on the earlier survey data. Figure 1 is a base map of a portion of the Weeks Island site showing the footprint of the oil storage facilities and locations of a portion of the monuments. This report provides an update, which includes additional measurements completed in the past two years. The changes in elevation, the rates of subsidence, as well as projections of future elevation changes are presented. Of specific interest to the DOE at Weeks Island is the areal and localized subsidence rate of the surface. At Weeks Island, owing to general high elevations, absolute elevations are not of paramount importance.

At Weeks Island and SPR sites in general, elevation changes are primarily due to creep closure of caverns. General subsidence on the scale of the site or portions thereof is seen

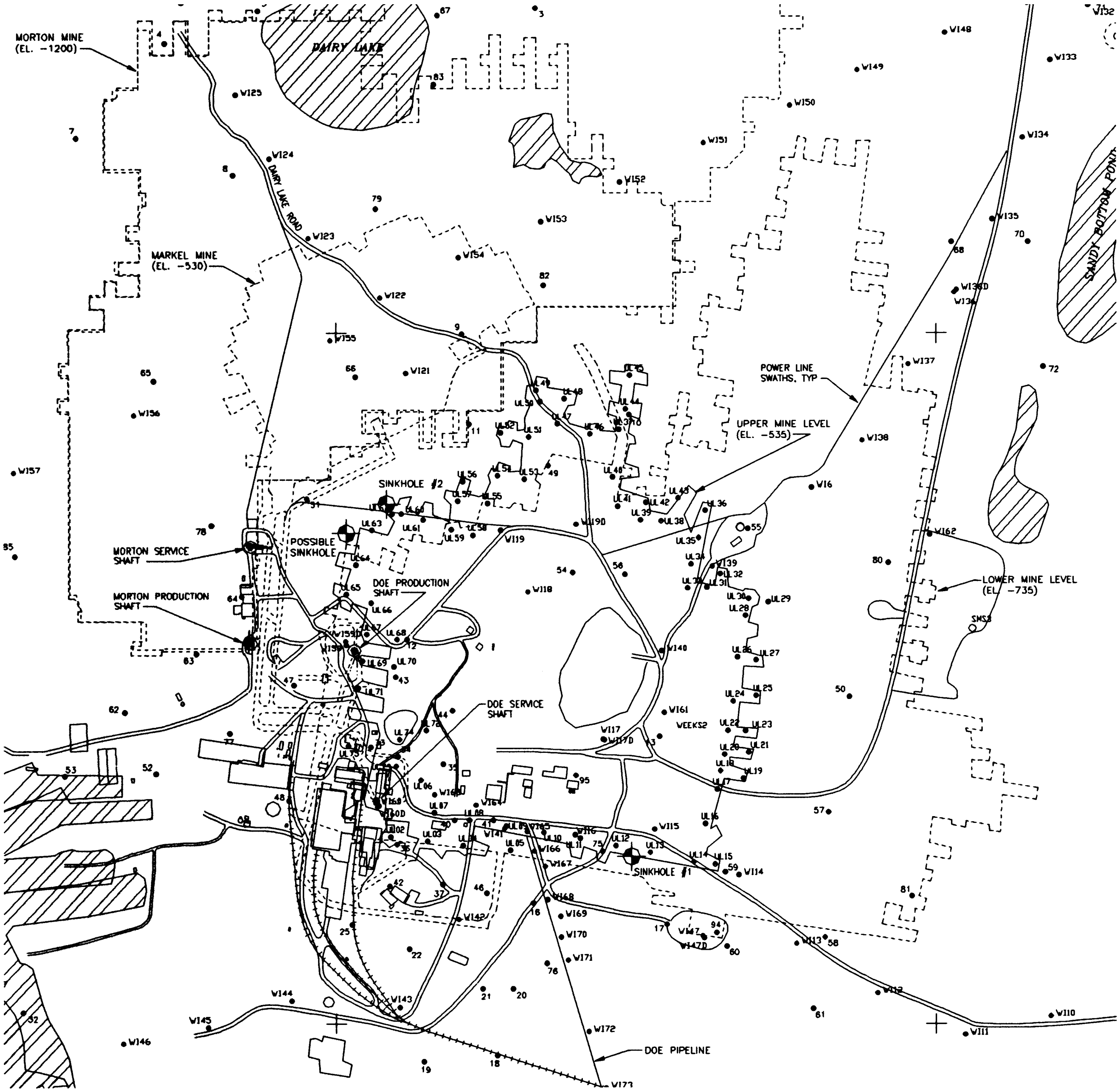

Figure 1. Site location map showing mine footprints and locations of newer subsidence monuments.

in the survey data taken. These subsidence measurements capture surface manifestations of creep closure of underground openings.

Subsidence is important because of general concerns for safety and site operations. Localized subsidence can adversely affect roads. Site facilities (electrical conduit, hoist equipment, valves, piping, etc.) could be damaged. Severe subsidence can impact future operations of the overall facility. The root cause (water leak into the mine) of localized subsidence at the Weeks Island facility has led to sinkhole development, emptying of the facility of oil, and planned decommissioning.

Procedures

Subsidence information is obtained in two ways, leveling surveys and visual observations. For the leveling surveys, elevation data represents the raw data. The measurements have been made at various time intervals; the current time interval is about 21 months. The most recent data set included 109 data points. The number of data points varies between measurements because loss of monuments occurs through destruction and damage. Three monuments recorded in the last survey were not included herein because the monuments were not located.

In practice, measurements of subsidence are difficult at best. At Weeks Island the reference is WI-1, installed before the February 1990 survey. WI-1 is located at the northeastern extremity of the survey network, outside the area affected by the oil storage and Morton mining; the elevation of WI-1 is verified at each survey. The elevation of Monument Disc 23v32 (the old baseline point) has in the past been surveyed and is currently used to verify the elevation of WI-1. Since 1988, the leveling surveys have been performed to Second-Order First-Class accuracy, with allowable vertical closure not to exceed 0.02 ft/mile$^{0.5}$ (6 mm/km$^{0.5}$). This means that for every mile long loop, the measurement must close to within .02 feet of the starting value. For loops less than a mile, the closure is accordingly smaller. Because WI-1 is so close to where measurements are made, the overall accuracy for measurements at the Weeks Island site is good. Furthermore, because survey loops are generally less than a mile, the accuracy is accordingly better than .02 feet. Osnes (1995) analyzed the surveying inaccuracies in the baseline data and found them to have a median value of about .01 ft and with approximately 95 per cent of the standard errors being less than 0.07 ft.

Subsidence over the large-scale area, (about three square miles) will likely be seen in the survey data taken. This type of subsidence captures gross effects of creep closure of underground openings. The surveys may also show precursors to localized subsidence.

Although observations from extensive surface traverses across the site are scheduled quarterly, localized subsidence and effects that manifest themselves as potential safety hazards are more likely to be seen by workers, as happened in 1998. However, the detailed long term subsidence measurements provided by the surveys is important, especially because it permits the long term extrapolation of elevation changes into the future and provides a metric to evaluate numerical analyses.

Site Observations

The author has regularly visited Weeks Island other salt mine shafts in the Gulf Coast region. Unpublished observations have been made of subsidence related deformation of surface structures as well as deformations and maintenance/repair of surface facilities in the immediate vicinity of shafts. What follows are descriptions of observations of deformations of site facilities at the Weeks Island site. Observations of the nature described are not uncommon at salt mine facilities.

In mid September inspections of the Production Shaft building at Weeks Island were made in conjunction with other site related work. Observations of the exterior of the building show striking compressional features on the northeast side of the building (displaced nail holes and folded and faulted fiberglass sheeting) as shown in Figure 2. The deformation is accommodated on the southwest side of the building with extensile features as indicated by stretched nail holes in the fiberglass sheeting, horizontal cracks in the basal blocks of the building, and vertical cracks in the airlock room as shown in Figure 3. In addition, this room may be separating from the rest of the structure.

These observations in themselves represent superficial damage to the building and do not indicate any loss in function of either the shaft building or the adjacent airlock building.

2a.

2b.

Figure 2a. Distant view of bent and sheared fiberglass panels on northeast side of hoist building.
Figure 2b. Compressed nail hole features on northeast side of hoist building.

2c. 2d.

Figure 2c. Oblique view of bent and sheared fiberglass panels on northeast side of hoist building.

Figure 2d. Close up view of sheared fiberglass sheathing and compressed nail hole features on northeast side of hoist building.

3a. 3b.

Figure 3a. Vertical crack in wall joining airlock room and hoist building (southwest side of hoist building).

Figure 3b. Horizontal foundation cracks on southwest side of hoist building.

3c.

3d.

Figure 3c. Vertical cracks in wall of airlock room on southwest side of hoist building.
Figure 3d. Stretched (extended) nail holes on southwest side of hoist building.

From the above observations, it appears that the Production Shaft building is leaning from the southwest to the northeast towards the center of subsidence over the mine. Evidence of the origin of this leaning can be seen inside the building. The floor may be described as an inner collar that comes right up to the shaft edge, and an outer collar area. In places there is a horizontal separation between the two collar segments as evidenced by Figure 4. Little to no relative vertical displacement was observed at this parted interface. The joint appeared to have been sealed at some time in the past with a bead of silicon joint compound. The joint now has more than half an inch of horizontal offset in places. Both the inner collar and outer collar are cracked, however, the outer collar appears to be much more heavily cracked.

The outer collar cracks first aroused workers attention more than a year ago, fostering a closer look at subsidence analyses (memo: Bauer and Linn to Berndsen dated 9/22/97). At that time it was determined that about 2 inches of differential subsidence had occurred across the building foundation during the past 40 years. Knowledge of the details of this differential subsidence and crack patterns in the pad could allow one to determine a cause and effect relationship between the subsidence and slab cracking.

The cracked concrete pad shows some vertical displacement immediately above the shaft liner where the inner collar appears to be lifted about an inch. This amount of displacement is consistent with the amount of cracking in the 3 to 4 foot thick concrete pad. The fiberglass panels inside the building are buckled in places, a stair rail is bent and a steel joint is cracked adjacent to a bent steel member (Figure 5). The function of all of these elements has been maintained. These observations are not unexpected given the pad cracking. Some leaning of the building frame has likely occurred, and certain non-structural elements have deformed in response.

Deformation immediately around the shaft itself was also observed (Figure 6). The lift guides are tied to massive horizontal timbers through an intervening steel plate. Immediately below where the guides are tied to the massive horizontal timber members there is a horizontal crack in each of the horizontal timber members. The crack in each opposing member appears widest (about 0.5“) at the center of the beam; the crack on both timbers dies out at the ends. It appears that the timbers are being pulled upward from where they are fastened to the vertical guides. It is adjacent to the cracked horizontal timbers that the inner collar appears to be lifted off the timbers about an inch. One corner of the inner collar had localized deformation in the form of cracking and shear displacement. No cracks were observed in either of the cross timbers, which run perpendicular to those connected to the lift guides. Also, it is important to note that no cracks were observed in the vertical lift guide timbers. The function of the system is again retained.

The very top of the shaft liner was examined with a fairly powerful flashlight while peering in from the inner collar. No cracks or other signs of degradation were visible in the shaft liner from this vantage point.

From the above observations it appears that the hoist structure is leaning from the southwest to the northeast as a result of some sort of differential settlement in the piling support for the structure. The hoist building is quite tall. This leaning has caused the exposed vertical structures to bend under gravitational loads, causing the shaft lift guides to pull up on the inner collar and horizontal timbers (causing cracking). The outer collar is cracking quite a bit because of underlying movements (concrete is weak in tension). The observed twisting of steel members and bending of inner and outer building sheathing is clearly their response to the deformation of structural elements to which they are attached.

Figure 4. Horizontal separation between inner and outer concrete collars, and cracks in collars inside Production Shaft hoist building.

Figure 5. Bent stair rail, bent steel member and cracked steel joint, and buckled fiberglass panels inside hoist building.

Figure 6a. Vertical lift guide connected to massive horizontal (cracked) timber. Note vertical separation between inner collar and the top of the timber (about an inch). Also note lack of deformation in timber perpendicular to the cracked one.

Figure 6b. Vertical lift guide connected to massive horizontal (cracked) timber on opposing side to Figure 6a. Note similar vertical separation between inner collar and the top of the timber (about an inch). Also note localized deformation in corner of concrete collar.

Previous work (Bauer and Linn, 1997) has been cited dictating a potential cause and effect relationship between subsidence and cracking in the concrete observed about a year ago. The direction of leaning of the hoist building is consistent with subsidence gradient from a direction of less subsidence on the mine edge (west side of hoist building) to more subsidence (east side of hoist building), directly over the mine.

As stated above, phenomena of this nature are not uncommon in the vicinity of shafts at salt mines.

During a recent quarterly surface inspection, evidence of possible effects of subsidence upon other DOE structures was observed (Bauer, 1998). Again these observed cracks in buildings and displacements in concrete walkways are likely the result of differential subsidence at the site.

Some observations were made inside the DOE main area, that are indicative of damage to surface facilities, which are also likely the result of surface subsidence. The brick fascia on the corners of the administration building has vertical cracks and attendant displacement. The concrete walkway on the south of the administration building and the one to the west of the old guard house has been cracked and displaced (Figure 7). A pipe support is sinking away from the pipe it is supposed to be supporting and a concrete abutment is rotating (Figure 8). There are cracks in the block work inside and outside of the door to the restroom next to the shop and shear cracks can be found in the tile work in the wall of the restroom (Figure 9). These observations should be expected in facilities which overlie ground across which considerable differential subsidence has been documented. The function of these facilities has not been effected by the deformations present. Further, the observations have led to an increased awareness of subsidence and its effects on surface facilities, an increase in the frequency of subsidence measurements, and a more aggressive attitude towards brine refill of the mine.

7a. 7b. 7c.

Figure 7. Administration building area: (a) cracking and horizontal displacement of brick fascia and (b) displacement of concrete walkway and (c) cracking and displacement of concrete walkway.

8a. 8b.

Figure 8. (a) pipe support separated from pipe it had been supporting, (b) concrete abutment that has undergone rotation.

Figure 9. Restroom near shop: cracks in block work near door, shear cracks in tile work.

Leveling Survey Results and Discussion

The results of measurements of elevation data since May of 1983 are given in Appendix 1. At Weeks Island the absolute values of vertical displacement are of interest, but more important in signaling potential problems are the subsidence rates and changes in subsidence rates with time. Subsidence rate data are displayed in Appendix 2 and Figures 10-14. The rates reported are annualized rates (ft/yr) for the time interval between measurements, and the figures presented consider longer time periods than a single measurement interval. Subsidence rates are due to creep closure of the underlying oil storage facility and the adjacent Morton Mine creep closure.

From 1983-1990 the area surveyed was relatively small (about a quarter of a square mile) compared to the DOE property boundary, and contained only about twenty measurement stations (Figure 10). The subsidence rate averaged between 0 and 0.1 ft/yr during this time period, but only one station was located over the center of the mine.

The survey station array has been gradually increased since 1990 to currently include over a hundred stations (109 in 1998), some of which are located over the middle of the DOE facility. Each year some stations are not found, destroyed, or buried.

Figure 11 presents subsidence rates for the entire nearly three square mile area currently studied for the 1990-1992 time period. The extended array encompasses the DOE facility, a portion of the Morton mine facility to the northwest as well as more stable areas to the east and southeast of the DOE facility. An important observation made consistent with these data is the continued rise of the Weeks Island salt dome. The rate of uplift is about 0.01 ft/yr. Also evident for the first time with these measurements are the greater rates of subsidence over the DOE mine area and rates over the Morton facility. These greater rates are recorded for the first time possibly because of the increased number of monuments added in this area and because of the greater accuracy ascribed to the survey.

From 1992 to 1995 (Figure 12) the subsidence rates appear very similar to the previous time period with the exception that a localized increased subsidence rate is observed in the northern part of the DOE facility area. This northern area “anomaly” disappears in the 1995-1996 time frame (Figure 13). The observed rates over the DOE and Morton facilities persist, with an increase up to 0.2-0.3 ft/yr range over the DOE facility reflecting the drawdown of the mine which started in November 1995.

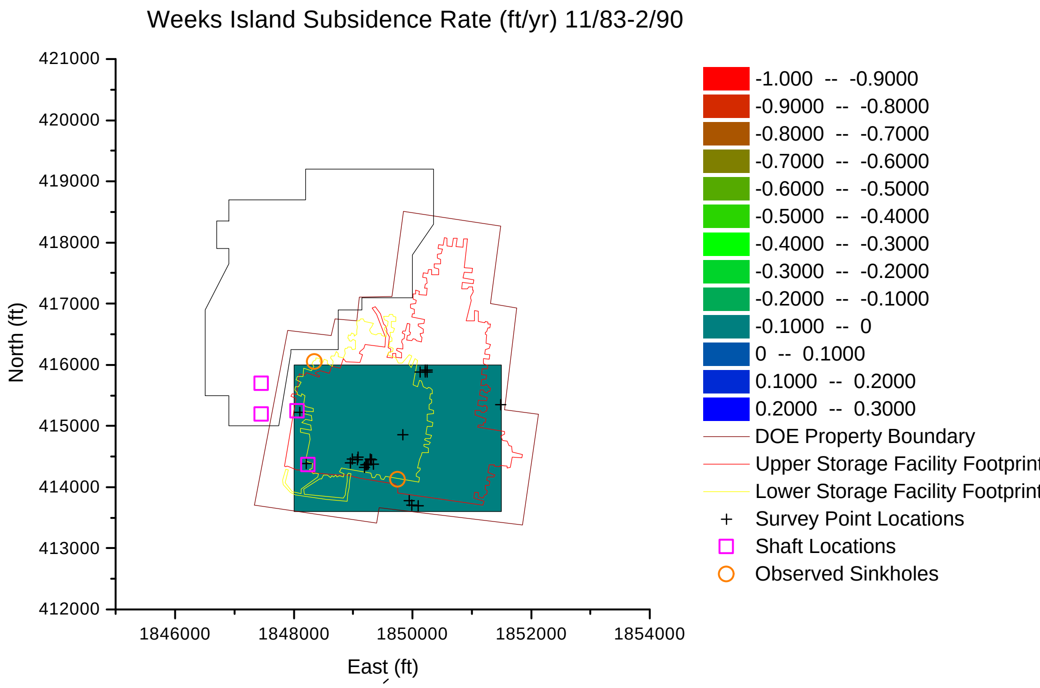

Figure 10. Weeks Island subsidence rates (ft/yr) 11/83-2/90.

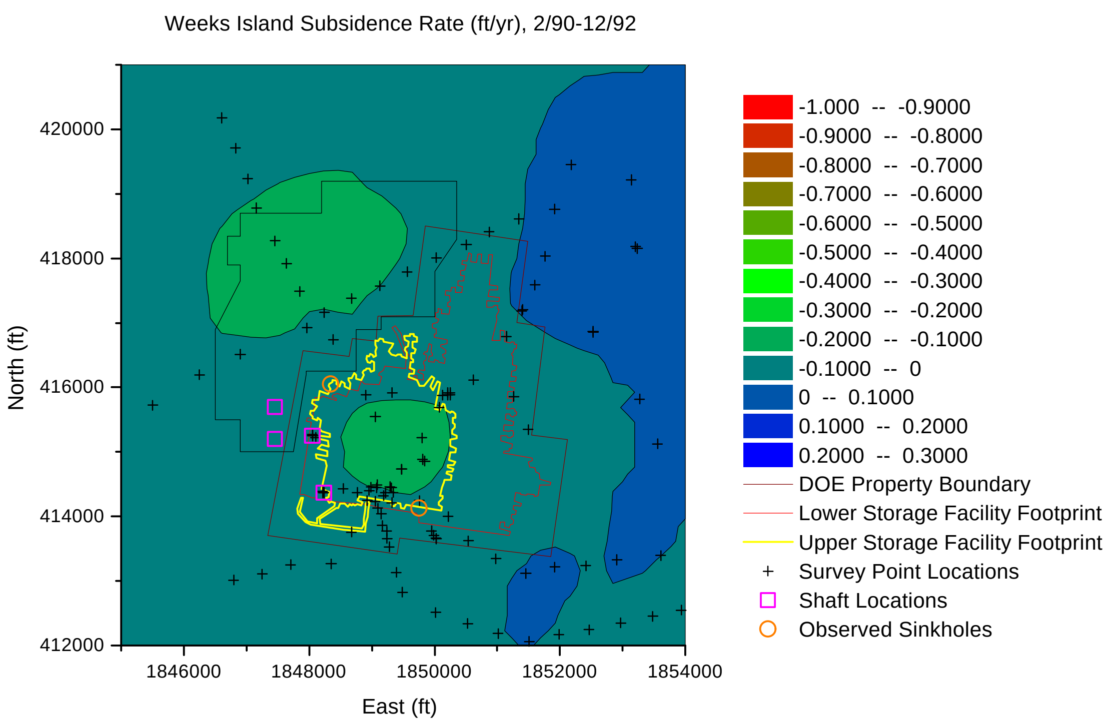

Figure 11. Weeks Island subsidence rates (ft/yr) 2/90-12/92.

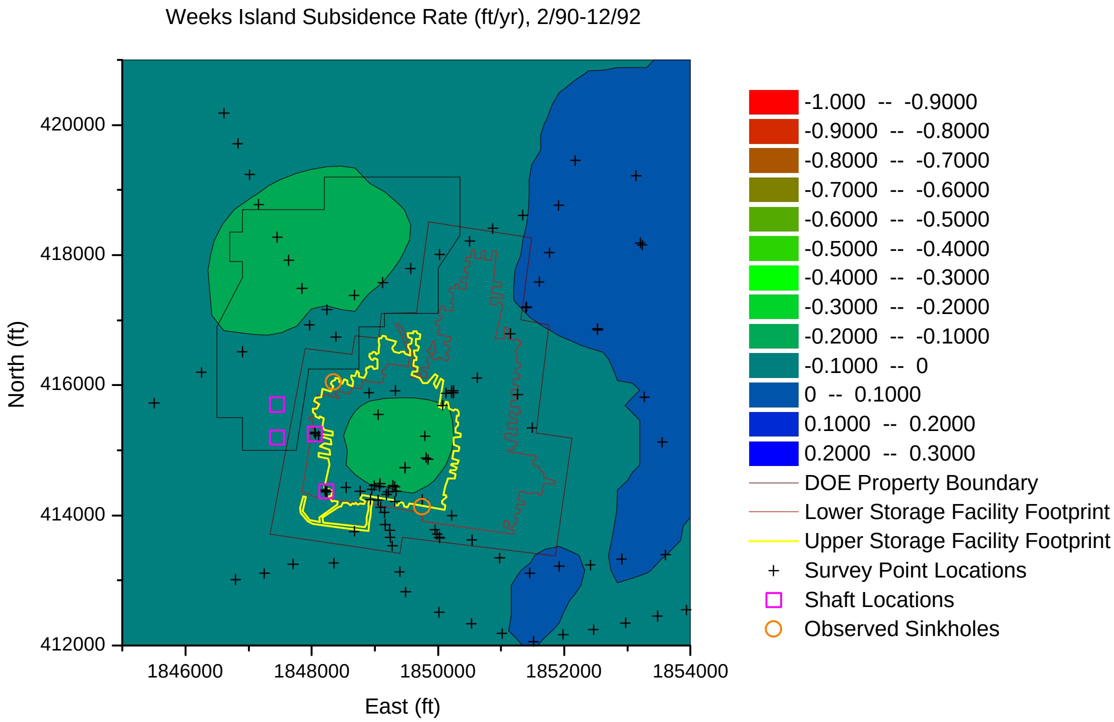

Figure 12. Weeks Island subsidence rates (ft/yr) 2/92-2/95.

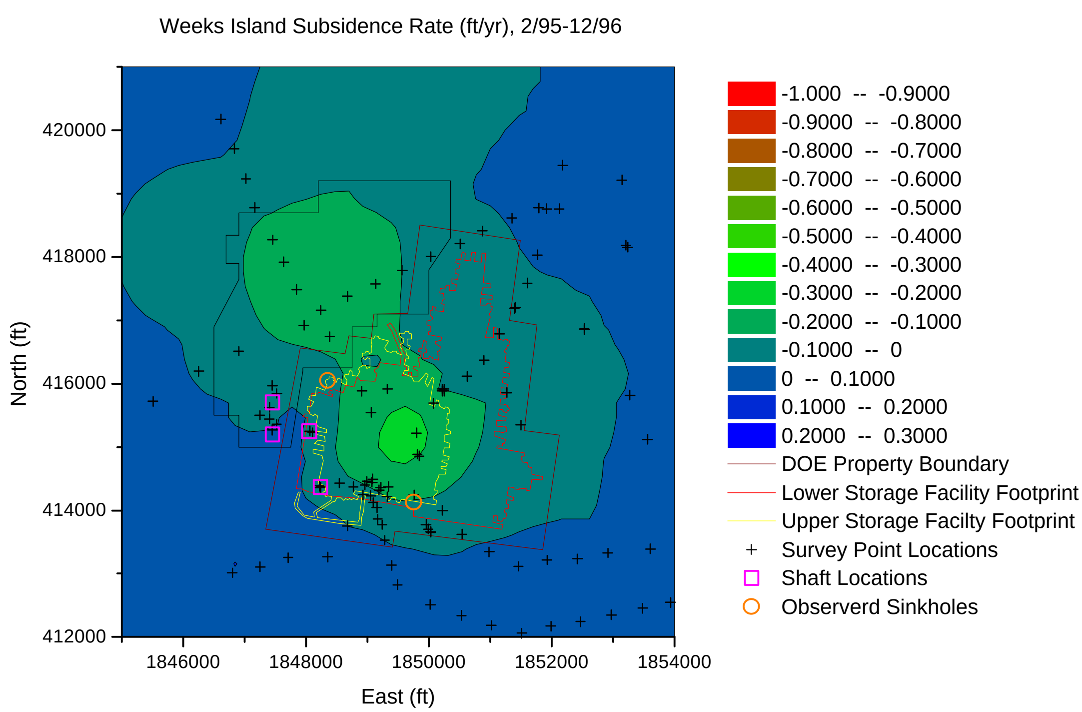

Figure 13. Weeks Island subsidence rates (ft/yr) 2/95-12/96.

Between 12/96 and 9/98 the subsidence rates over the DOE facility increased markedly (Figure 14). Maximum subsidence rates are near 1 ft/year (near subsidence monuments Weeks 2 and WI-61- see red contour area on Figure 14). Subsidence rate increases were observed for most of the DOE facility area, in the 0.3 to 0.5 ft/yr range. In summary, local rates increased by a factor of up to four to five, whereas overall rates increased by a factor of two to three. Subsidence rate increases of two to three are also observed to the northwest, over the Morton facility. The white triangles in Figure 14 represent stations that experienced a factor of three or greater increase in subsidence rate. In looking at the figure one must be careful to understand the relative amount of the increase in context with the absolute amount of increase. The high rate increases found over much of the

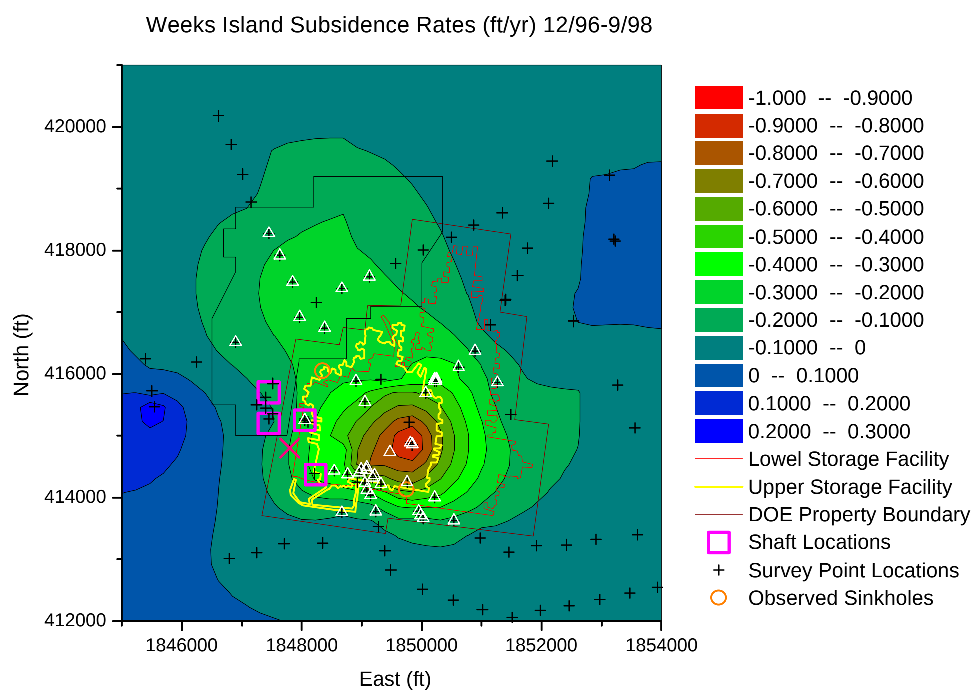

Figure 14. Weeks Island subsidence rates (ft/yr) 12/96-9/98.

DOE and Morton facilities are potentially due to emptying the mine and may in part be the result of the continued mining or an increase in extraction in the Morton mine.

The recent increase in subsidence rates is consistent with the data collected local to Sinkhole #1 (Appendix 3) for the time period of early-mid 1997. That data showed that subsidence near Sinkhole #1 was consistent with observed subsidence over other areas of the mine. At that time (prior to the most recent subsidence data), the increase in rates observed was believed attributable to the emptying of the mine of oil. For the recent measurements, increased subsidence is observed at the Weeks Island site predominantly over the oil storage facility and Morton facilities. The subsidence rate change over the

DOE facility is likely due to increased salt creep mine closure. This increase in mine closure rate is likely the result of the stress state and its changes in the mine and storage facility with time.

Since the mine was filled with oil in 1981, no access has been gained into the oil storage areas. Any thoughts on the causes for the observed subsidence patterns are guided by a combination of measurements and mechanical analysis. Large unknowns exist pertaining to what has physically happened in the DOE mine. Slabbing and rockfall have been postulated (Ehgartner, 1998). Mining has continued at the Morton facility, and the extraction history there of course affects the subsidence over the DOE facility (Ehgartner, 1998).

At the DOE facility, the stress state is determined by the facility depth, internal geometry, in situ stress, fill condition (oil filled, or partially oil filled, empty, brine filled or partially brine filled), and pillar condition with time. The depth and in situ stress state have remained relatively constant through the past 20 year study period. The internal geometry has also remained relatively constant, once DOE assumed ownership of the facility. The fill condition has changed with time. The mine was initially empty in 1982, was filled by 1983 and remained filled through 1996. At that time the mine emptying began and took 9 months to complete.

The stress state change during the emptying varies with mine depth and is determined by the "head" of oil back pressure when oil filled (or partially filled). Since that time (emptying) the mine has been at various levels of brine refill during the skimming phases, and again the stress state change during the brine refill varies with mine depth and is determined by the "head" of brine back pressure when brine filled (or partially filled). These stress changes would have resulted in a 60% subsidence rate increase (Hoffman,1994) and cannot fully account for the recent observed subsidence rate change. However, Hoffman's work does show agreement between calculated results and the 1996 subsidence data.

The brine used for refill has been about 80% saturated. This brine quality has probably facilitated some dissolution of the mine surfaces. If much of this dissolution took place on pillars, decreasing their cross sectional areas would have caused a local increase in the stress state. The fairly uniform distribution of high rates of subsidence rate increase (Figure 14) indicates that if this is the operable mechanism, then the dissolution and consequent deformation are widespread. This and the possibility that the pillars could have experienced some damage when the oil was withdrawn are the subject of ongoing analyses (Ehgartner, 1998).

Summary and Conclusions

The elevation change data measured at the Weeks Island SPR site over the last 16+ years has been studied and analyzed. The subsidence rate has increased slightly during the past several, recently the rate has increased more dramatically. The recent increase comes at a time when the Strategic Petroleum Reserve (SPR) storage mine had been emptied of oil and was in the process of being refilled with brine.

Damage to surface structures that has been observed during the past 12-18 months is attributed to the continued subsidence and differential subsidence across structures. This type of deformation is not uncommon at other shaft building facilities above Gulf Coast salt mines. Damage of this type should be anticipated at SPR facilities wherever differential subsidence of sufficient magnitude across a facility element may occur. None of the observed damage has caused loss of function of the various facilities.

This report points to a continued need to routinely collect a complete set of elevation data at SPR facilities. The data collected has provided information to the project that was unanticipated by previous analyses. Thus, the data can be used not only to constrain and compare with future analyses, but also as an important diagnostic tool.

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Appendix 1

Historic Elevation Measurements at Weeks Island

ELEVATION DATA, (feet)

PT. #	East (ft)	North (ft)	MAY 83 0	NOV 6	MAR 84 10	OCT 84 17	APR 86 35	JUN 87 49	OCT 88 65	FEB 90 81	FEB 91 93	FEB 92 105	DEC 92 115	MAR 94 130	FEB 95 141	JAN 96 152	DEC 96 163	SEP 98 183	DEC 98 186
1	1850212.3	415915.9	131.60	131.53	131.47	131.42	131.23	131.14	131.15	131.03	131.00	130.97	130.96	130.72	130.68	130.60	130.52	129.86	129.85
2	1850213.1	415883.8	131.55	131.47	131.41	131.35	131.16	131.07	131.08	130.96	130.90	130.88	130.85	130.62	130.66	130.49	130.42	129.72	129.72
3	1850245.2	415882.9	131.45	131.38	131.31	131.26	131.07	130.97	130.99	130.86	130.79	130.75	130.75	130.50	130.52	130.39	130.30	129.57	129.54
4	1850245.5	415917.4	131.55	131.48	131.41	131.37	131.19	131.10	131.11	130.99	130.92	130.86	130.90	130.65	130.61	130.53	130.44	129.77	129.68
6	1849284.4	414463.2	101.74	101.64	101.57	101.43	101.20	101.08	100.95	100.79	100.61	100.47	100.39	100.16	#N/A	#N/A	#N/A	destroyed	destroyed
7	1849312.9	414442.4	101.77	101.68	101.60	101.43	101.24	101.12	101.01	100.84	100.66	100.53	100.45	100.22	#N/A	#N/A	#N/A	#N/A	destroyed
8	1849336.2	414374.6	101.04	100.96	100.89	100.73	100.54	100.44	100.34	100.19	100.03	99.91	99.87	99.63	99.55	99.42	99.25	#N/A	destroyed
9	1849257.9	414379.9	99.95	99.88	99.81	99.67	99.47	99.37	99.27	#N/A	#N/A	99.40	99.33	#N/A	#N/A	#N/A	#N/A	#N/A	destroyed
10	1849236.7	414367.7	99.97	99.87	99.81	99.68	99.49	99.39	99.30	#N/A	#N/A	99.39	99.34	#N/A	#N/A	#N/A	#N/A	#N/A	destroyed
11	1849212.0	414365.5	99.77	99.67	99.61	99.48	99.29	99.20	99.11	98.97	98.82	98.71	98.63	98.45	98.38	98.26	98.12	97.02	96.82
12	1849184.2	414321.4	98.86	98.78	98.72	98.59	98.43	98.35	98.26	98.18	98.04	97.95	97.90	97.72	97.65	97.55	97.44	96.47	96.30
13	1849074.0	414442.0	99.90	99.81	99.75	99.63	99.43	99.31	99.26	99.10	98.95	98.76	98.68	98.59	98.48	98.38	98.27	97.09	96.84
15	1849080.0	414493.5	99.90	99.82	99.75	99.47	99.27	99.16	99.06	99.05	98.83	98.55	98.48	98.50	98.42	98.10	98.00	96.75	96.50
22	1848953.2	414399.9	101.29	101.25	101.18	101.08	100.90	100.83	100.77	100.66	100.52	100.42	100.41	100.25	100.18	100.07	99.97	99.00	98.84
23	1848985.2	414459.0	100.84	100.78	100.71	100.59	100.39	100.31	100.23	100.10	99.95	99.84	99.79	99.60	99.52	99.40	99.26	98.19	97.98
29	1850091.0	413692.9	71.28	71.22	71.16	71.12	71.07	71.09	69.09	70.22	70.16	70.11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
30	1849988.3	413709.3	69.73	69.67	69.61	69.57	69.54	69.56	69.10	69.55	69.49	69.43	69.43	69.02	69.02	69.00	69.03	68.88	68.84
35	1848103.1	415227.1	77.45	77.37	77.32	77.19	77.19	77.20	#N/A	77.64	#N/A	77.54	77.49	77.27	77.27	77.34	77.49	77.03	77.02
36	NA	NA	#N/A	#N/A	#N/A	#N/A	65.73	65.72	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
SMS 1	1850127.3	415877.5	130.04	129.97	129.92	129.85	129.67	129.57	129.59	129.47	#N/A	129.30	129.29	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
SMS 2	1849951.4	413780.0	65.53	65.45	65.39	65.34	65.28	65.26	65.22	65.18	#N/A	65.05	65.05	64.98	64.95	64.90	64.86	64.39	64.31
SMS 3	1851492.3	415346.8	37.08	37.09	37.08	36.91	37.03	37.02	37.01	36.99	#N/A	36.94	36.95	36.91	36.90	36.98	36.81	36.61	36.58
SMS 4	1848213.1	414386.5	53.92	53.83	53.79	53.63	53.69	53.71	#N/A	53.70	#N/A	53.58	53.62	53.65	53.57	53.50	53.84	53.25	53.23
SMS 5	1847866.6	415024.7	#N/A	#N/A	44.43	44.26	44.35	#N/A	#N/A	#N/A	#N/A	44.17	44.14	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
23V32	*29-48-48NLAT	*91-47-47WLON	11.84	11.84	11.84	11.84	11.84	11.84	11.84	11.84	11.84	11.84	#N/A	11.84	11.84	11.84	#N/A	#N/A	#N/A
23V33	*29-49-29NLAT	*91-47-39WLON	#N/A	#N/A	#N/A	#N/A	37.04	37.07	#N/A	37.08	37.09	37.07	37.08	37.06	37.07	37.06	37.06	37.07	37.04
WEEKS 2	1849838.9	414859.4	#N/A	#N/A	#N/A	#N/A	127.84	127.65	127.46	127.25	#N/A	126.87	126.77	126.47	126.32	126.13	125.80	124.07	123.76
WI-1	1853135.3	419215.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	40.20	40.20	40.20	40.20	40.20	40.20	40.20	40.20	40.20	40.20
WI-2	1853233.5	418156.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	39.57	39.57	39.57	39.57	39.57	39.57	39.57	39.57	39.57	39.55
WI-3	1852533.3	416854.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	33.04	33.04	33.03	33.04	33.02	33.04	33.02	33.04	33.04	33.01
WI-4	1853269.0	415819.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	40.95	40.94	40.93	40.95	40.93	40.95	40.93	40.96	40.94	40.93
WI-5	1853554.8	415124.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	26.75	26.74	26.73	26.74	26.73	26.74	26.73	26.76	26.74	26.72
WI-6	1850618.9	416117.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	114.91	114.86	114.78	114.79	114.67	114.64	114.57	114.49	113.95	113.88
WI-7	1853604.8	413394.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	30.44	30.42	30.41	30.43	30.41	30.43	30.42	30.44	30.40	30.39
WI-8	1852908.2	413326.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	33.64	33.64	33.64	33.65	33.63	33.65	33.65	33.69	33.64	33.61
WI-9	1852414.7	413233.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	36.34	36.35	36.34	36.36	36.34	36.35	36.36	36.39	36.35	36.31
WI-10	1851916.7	413219.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	57.48	57.48	57.47	57.50	57.47	57.48	57.49	57.53	57.48	57.45
WI-11	1851452.8	413115.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	60.15	60.14	60.14	60.15	60.14	60.15	60.15	60.19	60.13	60.10
WI-12	1850978.4	413346.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	70.24	70.24	70.15	70.25	70.22	70.23	70.22	70.25	70.17	70.15
WI-13	1850536.2	413622.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	83.89	83.85	83.83	83.83	83.76	83.76	83.73	83.71	83.42	83.35
WI-14	1850219.6	413997.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	93.52	93.43	93.35	93.33	93.19	93.14	93.07	92.95	92.23	92.10
WI-15	1849754.7	414243.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	83.47	83.32	83.18	83.12	82.91	82.83	82.69	82.49	81.34	81.13
WI-16	1849316.7	414214.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	84.08	83.97	83.88	83.87	83.72	83.68	83.59	83.50	82.74	82.60
WI-17	1849471.0	414737.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	104.70	104.51	104.31	104.19	103.90	103.77	#N/A	#N/A	#N/A	#N/A
WI-18	1849056.4	415548.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	114.92	114.82	114.71	114.68	114.50	114.45	114.33	114.22	113.49	113.36
WI-19	1848905.3	415883.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	93.76	93.70	93.62	93.62	93.49	93.47	93.37	93.31	92.87	92.81

WI-20	NA	NA	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
WI-21	1848381.7	416741.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	88.64	88.55	88.41	88.41	88.25	88.14	87.97	87.91	87.53	87.52
WI-22	1848239.0	417159.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	74.31	74.18	73.94	73.88	73.62	73.46	73.29	73.15	72.65	72.62
WI-23	1847846.7	417489.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	68.21	68.08	67.82	67.75	67.51	67.37	67.21	67.07	66.58	66.54
WI-24	1847635.7	417920.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	65.20	65.10	64.89	64.75	64.64	64.53	64.40	64.32	63.93	63.91
WI-25	1847452.8	418271.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	53.76	53.71	53.57	53.48	53.45	53.39	53.27	53.29	53.03	53.04
WI-26	1847160.2	418779.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	66.46	66.46	66.38	66.34	66.41	66.39	66.34	66.39	66.25	66.28
WI-27	1847016.7	419233.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	35.43	35.44	35.36	35.33	35.41	35.40	35.38	35.43	35.31	35.34
WI-28	1846825.7	419713.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	5.13	4.83	5.07	5.07	5.12	5.12	5.09	5.16	5.04	5.06
WI-29	1846609.0	420178.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.97	2.99	2.93	2.90	2.98	2.99	2.96	3.02	2.91	2.94
WI-30	1852177.9	419450.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	41.46	41.47	41.46	41.48	41.46	41.47	41.47	41.47	41.47	41.47
WI-31	1851788.1	418777.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	49.58	49.60	49.59	#N/A	50.53	50.55	50.55	50.56	50.54	50.54
WI-32	1852120.3	418762.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	37.52	37.54	37.53	#N/A	37.50	37.52	37.53	37.54	37.52	37.52
WI-33	1851914.1	418762.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	38.20	38.22	38.21	38.24	38.20	38.23	38.22	38.23	38.24	38.22
WI-34	1851764.8	418033.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	33.49	33.51	33.50	33.52	33.49	33.52	33.52	33.54	33.51	33.51
WI-35	1851599.9	417590.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	39.88	39.90	39.89	39.92	39.89	39.91	39.91	39.92	39.90	39.91
WI-36	1851391.7	417190.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51.70	51.71	51.70	51.72	51.69	51.71	51.71	51.72	51.69	51.70
WI-37	1851144.2	416792.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	48.29	48.30	48.27	48.29	48.25	48.26	48.25	48.23	48.16	48.16
WI-38	1850893.5	416374.2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	57.54	57.52	57.46	#N/A	56.20	56.19	56.16	56.11	55.83	55.77
WI-39	1850074.9	415690.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	125.93	125.85	125.73	125.71	125.52	125.47	125.37	125.24	124.46	124.33
WI-40	1849796.3	415222.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	120.72	120.57	120.40	120.31	120.05	119.96	119.80	119.55	118.25	118.00
WI-41	1848925.0	414245.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	83.41	83.32	83.26	83.25	83.13	83.10	83.04	82.98	82.37	82.26
WI-42	1848671.7	413755.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	58.23	58.22	58.16	58.22	58.17	58.16	58.17	58.20	58.10	58.09
WI-43	1848347.9	413267.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51.55	51.54	51.49	51.52	51.51	51.52	51.53	51.56	51.51	51.49
WI-44	1847704.6	413254.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	40.02	40.01	39.96	39.97	39.97	39.99	39.98	40.02	39.96	39.97
WI-45	1847251.6	413106.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	28.70	28.69	28.64	28.65	28.65	28.50	28.67	28.71	28.65	28.67
WI-46	1846794.4	413015.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	10.49	10.49	10.43	10.44	10.45	10.46	10.46	10.50	10.45	10.47
WI-47	1850022.1	413663.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	64.35	64.29	64.24	64.26	64.21	64.18	64.15	64.15	63.87	63.82
WI-48	1851344.6	418614.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	104.23	104.24	104.18	104.24	104.21	104.22	104.21	104.24	104.17	104.17
WI-49	1850868.8	418408.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	110.68	110.67	110.60	110.55	110.61	110.61	110.59	110.62	110.52	110.54
WI-50	1850502.3	418213.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	113.65	113.59	113.49	113.47	113.46	113.44	113.39	113.39	113.24	113.23
WI-51	1850028.2	418007.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	94.57	94.46	94.32	94.33	94.23	94.17	94.06	94.04	93.82	93.82
WI-52	1849565.8	417792.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	58.22	58.09	57.92	57.89	57.73	57.59	57.44	57.37	57.09	57.07
WI-53	1849129.3	417577.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	64.94	64.81	64.61	64.58	64.31	64.13	63.95	63.86	63.49	63.47
WI-54	1848672.4	417382.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	82.05	81.92	81.70	81.64	81.33	81.16	80.98	80.86	80.38	80.35
WI-55	1847965.5	416923.2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	69.42	69.29	69.08	68.99	68.85	68.72	68.56	68.44	67.99	67.92
WI-56	1846900.0	416512.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	21.43	21.33	21.20	21.13	21.11	21.06	21.00	20.99	20.74	20.66
WI-57	1846251.6	416197.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	19.45	19.42	19.37	19.33	19.38	19.34	19.33	19.38	19.26	19.20
WI-58	1845505.9	415724.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	11.07	11.05	11.01	10.99	11.06	11.02	11.02	11.03	10.99	10.99
WI-59	1848054.3	415253.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	74.82	74.79	74.73	74.67	74.66	74.66	74.61	74.58	74.21	74.17
WI-60	1848234.4	414369.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51.14	51.11	51.02	51.04	51.08	51.00	50.93	50.90	covered	covered
WI-61	1849809.2	414883.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	125.35	125.16	124.95	124.86	124.54	124.41	124.22	123.90	122.16	121.84
WI-62	1851261.4	415860.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	31.04	31.03	31.00	31.00	30.95	30.94	30.93	30.87	30.68	30.65
WI-63	1848539.4	414432.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	82.10	82.04	81.90	81.91	81.90	81.79	81.73	81.67	81.02	80.95
WI-64	1848767.5	414374.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	79.27	79.20	79.04	79.07	78.94	78.90	78.82	78.74	78.01	77.88
WI-65	1849051.5	414232.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	90.62	90.52	90.45	90.44	90.31	90.28	90.18	90.15	89.49	89.37
WI-66	1849090.2	414124.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	87.24	87.16	87.11	87.11	87.01	87.00	86.92	86.91	86.43	86.35
WI-67	1849149.6	414042.2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	82.51	#N/A	82.39	82.39	82.28	82.27	82.20	82.18	81.71	81.62
WI-68	1849164.0	413862.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	63.88	63.80	63.74	63.72	63.62	63.59	63.52	63.49	NOT LOCATED	cnl
WI-69	1849235.9	413772.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	53.63	53.58	53.56	53.58	53.53	53.53	53.50	53.52	53.35	53.31
WI-70	1849239.0	413657.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	50.54	50.50	50.48	50.50	50.45	50.47	50.44	#N/A	#N/A	#N/A

WI-71	1849278.5	413530.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	49.23	49.19	49.18	49.20	49.16	49.17	49.15	49.19	49.06	49.04
WI-72	1849392.7	413134.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	48.43	48.39	48.39	48.36	48.38	48.41	48.39	48.44	48.37	48.35
WI-73	1849487.8	412823.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	40.26	40.23	40.22	40.25	40.21	40.24	40.21	40.28	40.21	40.19
WI-74	1850016.4	412512.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	27.71	27.68	27.66	27.69	27.65	27.67	27.65	27.72	27.65	27.62
WI-75	1850529.5	412341.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	22.17	22.15	22.14	22.15	22.12	22.13	22.12	22.19	22.12	22.09
WI-76	1851013.1	412184.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	19.46	19.43	19.42	19.44	19.42	19.42	19.40	19.46	19.40	19.38
WI-77	1851507.7	412063.2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	21.37	21.35	21.34	21.36	21.35	21.34	21.32	21.39	21.33	21.32
WI-78	1851982.1	412173.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	13.14	13.11	13.11	13.13	13.11	13.10	13.09	13.15	13.09	13.08
WI-79	1852463.8	412242.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	13.51	13.49	13.48	13.50	13.49	13.47	13.46	13.52	13.46	13.44
WI-80	1852970.4	412348.6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	7.26	7.24	7.22	7.25	7.24	7.23	7.21	7.25	7.21	7.20
WI-81	1853477.0	412454.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3.39	3.37	3.36	3.36	3.37	3.36	3.34	3.39	3.34	3.33
WI-82	1853930.1	412545.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.41	2.39	2.39	2.40	2.39	2.40	2.38	2.41	2.20	2.36
WI-2 DEEP	1853202.3	418186.8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	41.89	41.93	41.93	41.93	41.95	41.96	41.98	42.02	42.04	42.00
WI-3 DEEP	1852529.5	416870.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	33.33	33.39	33.38	33.41	33.39	33.41	33.40	33.42	33.44	33.41
WI-17 DEEP	1849479.0	414734.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	104.84	104.67	104.46	104.35	104.06	103.76	#N/A	#N/A	#N/A	#N/A
WI-19 DEEP	1849321.6	415916.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	111.90	#N/A	111.75	111.74	111.61	111.58	111.49	111.42	111.00	110.92
WI-36 DEEP	1851404.7	417203.7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51.40	#N/A	51.39	51.41	51.39	51.41	51.40	51.41	51.38	51.39
WI-47 DEEP	1850029.4	413652.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	64.32	64.27	64.22	64.24	64.18	64.16	64.13	64.13	63.84	63.79
WI-59 DEEP	1848049.9	415275.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	74.57	74.53	74.47	74.42	74.40	74.41	74.36	#N/A	73.94	73.90
WI-60 DEEP	1848223.9	414365.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	50.99	50.97	50.88	50.89	50.94	50.86	50.80	50.76	50.50	50.49
MORTON 1	1847400.1	415447.1												60.51	60.45	60.39	60.35	60.22	60.19
MORTON 2	1847400.5	415628.2												60.73	60.66	60.59	60.53	60.36	60.35
MORTON 3	N/A	N/A																	
MORTON 4	N/A	N/A																	
COGO A	1847520.1	415356.5												65.25	65.19	65.14	65.11	64.98	64.96
COGO C	1847451.5	415270.8												63.13	63.07	63.02	63.00	62.89	62.86
COGO D	1847521.2	415847.2												65.32	65.24	65.16	65.09	64.87	64.86
COGO 11	1847450.0	415972.2													64.04	63.97	63.87	NOT LOCATED	63.60
COGO 12	1847816.3	417444.2													NOT LOCATED	NOT LOCATED	NOT LOCATED	NOT LOCATED	
COGO 13	1847246.9	415502.2													61.01	61.12	61.07	60.94	60.92
COE 924	1845390.1	416246.8														6.25	6.25	6.22	6.20
COE 923	1845541.3	415469.8														12.90	12.19	12.87	12.84

Appendix 2

Historic Subsidence Rates at Weeks Island

SUBSIDENCE RATE (ft/yr)

PT. #	East (ft)	North (ft)	NOV 83 ANNUAL RATE	MAR 84 ANNUAL RATE	OCT 84 ANNUAL RATE	APR 86 ANNUAL RATE	JUN 87 ANNUAL RATE	OCT 88 ANNUAL RATE	FEB 90 ANNUAL RATE
1	1850212.3	415915.9	-0.035	-0.020	-0.029	-0.285	-0.105	0.013	-0.154
2	1850213.1	415883.8	-0.040	-0.020	-0.035	-0.285	-0.105	0.013	-0.164
3	1850245.2	415882.9	-0.035	-0.023	-0.029	-0.285	-0.117	0.027	-0.172
4	1850245.5	415917.4	-0.035	-0.023	-0.023	-0.270	-0.105	0.013	-0.165
6	1849284.4	414463.2	-0.050	-0.023	-0.082	-0.345	-0.140	-0.173	-0.219
7	1849312.9	414442.4	-0.045	-0.027	-0.099	-0.285	-0.140	-0.147	-0.231
8	1849336.2	414374.6	-0.040	-0.023	-0.093	-0.285	-0.117	-0.133	-0.199
9	1849257.9	414379.9	-0.035	-0.023	-0.082	-0.300	-0.117	-0.133	
10	1849236.7	414367.7	-0.050	-0.020	-0.076	-0.285	-0.117	-0.120	
11	1849212.0	414365.5	-0.050	-0.020	-0.076	-0.285	-0.105	-0.120	-0.187
12	1849184.2	414321.4	-0.040	-0.020	-0.076	-0.240	-0.093	-0.120	-0.109
13	1849074.0	414442.0	-0.045	-0.020	-0.070	-0.300	-0.140	-0.067	-0.216
15	1849080.0	414493.5	-0.040	-0.023	-0.163	-0.300	-0.128	-0.133	-0.011
22	1848953.2	414399.9	-0.020	-0.023	-0.058	-0.270	-0.082	-0.080	-0.153
23	1848985.2	414459.0	-0.030	-0.023	-0.070	-0.300	-0.093	-0.107	-0.177
29	1850091.0	413692.9	-0.030	-0.020	-0.023	-0.075	0.023	-2.667	1.505
30	1849988.3	413709.3	-0.030	-0.020	-0.023	-0.045	0.023	-0.613	0.593
35	1848103.1	415227.1	-0.040	-0.017	-0.076	0.000	0.012		
SMS 1	1850127.3	415877.5	-0.035	-0.017	-0.041	-0.270	-0.117	0.027	-0.165
SMS 2	1849951.4	413780.0	-0.040	-0.020	-0.029	-0.090	-0.023	-0.053	-0.052
SMS 3	1851492.3	415346.8	0.005	-0.003	-0.099	0.180	-0.012	-0.013	-0.027
SMS 4	1848213.1	414386.5	-0.045	-0.013	-0.093	0.090	0.023		
SMS 5	1847866.6	415024.7			-0.099	0.135			
WKS 2	1849838.9	414859.4						-0.255	-0.279

					SUBSIDENCE RATE (ft/yr)						
			FEB 91	FEB 92	DEC 92	MAR 94	FEB 95	JAN 96	DEC 96	Sep-98	Dec-98
			ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL
PT. #	East (ft)	North (ft)	RATE	RATE	RATE	RATE	RATE	RATE	RATE	RATE	RATE
1	1850212.3	415915.9	-0.031	-0.032	-0.013	-0.294	-0.039	-0.072	-0.077	-0.395	-0.012
2	1850213.1	415883.8	-0.054	-0.020	-0.030	-0.282	0.031	-0.148	-0.070	-0.421	-0.004
3	1850245.2	415882.9	-0.068	-0.043	0.002	-0.314	0.020	-0.124	-0.077	-0.439	-0.144
4	1850245.5	415917.4	-0.063	-0.062	0.036	-0.316	-0.041	-0.072	-0.080	-0.403	-0.352
6	1849284.4	414463.2	-0.179	-0.134	-0.072	-0.285					#N/A
7	1849312.9	414442.4	-0.176	-0.133	-0.064	-0.286					#N/A
8	1849336.2	414374.6	-0.162	-0.122	-0.030	-0.302	-0.077	-0.114	-0.160		#N/A
9	1849257.9	414379.9			-0.063						#N/A
10	1849236.7	414367.7			-0.046						#N/A
11	1849212.0	414365.5	-0.148	-0.109	-0.068	-0.221	-0.072	-0.106	-0.129	-0.658	-0.800
12	1849184.2	414321.4	-0.138	-0.091	-0.043	-0.219	-0.068	-0.095	-0.099	-0.581	-0.692
13	1849074.0	414442.0	-0.153	-0.186	-0.065	-0.114	-0.099	-0.095	-0.100	-0.707	-0.996
15	1849080.0	414493.5	-0.224	-0.276	-0.063	0.036	-0.080	-0.290	-0.093	-0.749	-1.004
22	1848953.2	414399.9	-0.137	-0.095	-0.010	-0.206	-0.060	-0.101	-0.094	-0.582	-0.644
23	1848985.2	414459.0	-0.151	-0.108	-0.044	-0.239	-0.068	-0.110	-0.127	-0.643	-0.836
29	1850091.0	413692.9	-0.062	-0.049							#N/A
30	1849988.3	413709.3	-0.058	-0.053	-0.003	-0.509	-0.008	-0.012	0.029	-0.093	-0.148
35	1848103.1	415227.1			-0.040	-0.274	-0.002	0.060	0.138	-0.281	-0.060
SMS 1	1850127.3	415877.5			-0.011						#N/A
SMS 2	1849951.4	413780.0			-0.002	-0.085	-0.028	-0.044	-0.041	-0.278	-0.320
SMS 3	1851492.3	415346.8			0.005	-0.050	-0.011	0.079	-0.160	-0.119	-0.100
SMS 4	1848213.1	414386.5			0.034	0.041	-0.079	-0.056	0.311	-0.358	-0.056
SMS 5	1847866.6	415024.7			-0.026						#N/A
WKS 2	1849838.9	414859.4			-0.082	-0.380	-0.135	-0.170	-0.302	-1.039	-1.244
WI-1	1853135.3	419215.5	0.006	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WI-2	1853233.5	418156.6	0.004	-0.007	0.003	-0.006	0.005	-0.006	0.004	0.003	-0.080
WI-3	1852533.3	416854.0	0.002	-0.019	0.012	-0.026	0.020	-0.021	0.015	0.004	-0.136
WI-4	1853269.0	415819.5	-0.003	-0.017	0.017	-0.019	0.013	-0.012	0.019	-0.007	-0.064
WI-5	1853554.8	415124.9	-0.009	-0.013	0.014	-0.017	0.009	-0.009	0.027	-0.014	-0.052
WI-6	1850618.9	416117.0	-0.048	-0.078	0.004	-0.144	-0.030	-0.058	-0.079	-0.323	-0.268
WI-7	1853604.8	413394.6	-0.017	-0.008	0.010	-0.023	0.017	-0.006	0.022	-0.025	-0.044
WI-8	1852908.2	413326.5	0.002	-0.001	0.013	-0.026	0.014	0.006	0.030	-0.025	-0.128
WI-9	1852414.7	413233.7	0.001	-0.003	0.013	-0.024	0.010	0.007	0.027	-0.020	-0.176
WI-10	1851916.7	413219.6	-0.002	-0.004	0.020	-0.030	0.009	0.007	0.038	-0.033	-0.116
WI-11	1851452.8	413115.7	-0.006	-0.004	0.013	-0.019	0.009	0.006	0.028	-0.036	-0.092
WI-12	1850978.4	413346.6	-0.008	-0.091	0.086	-0.038	0.009	-0.006	0.024	-0.044	-0.112
WI-13	1850536.2	413622.4	-0.033	-0.026	0.004	-0.086	-0.006	-0.022	-0.024	-0.174	-0.256
WI-14	1850219.6	413997.0	-0.085	-0.083	-0.015	-0.175	-0.043	-0.065	-0.110	-0.431	-0.536
WI-15	1849754.7	414243.6	-0.157	-0.135	-0.050	-0.260	-0.082	-0.125	-0.184	-0.689	-0.828
WI-16	1849316.7	414214.8	-0.109	-0.085	-0.016	-0.186	-0.037	-0.079	-0.086	-0.454	-0.572
WI-17	1849471.0	414737.0	-0.188	-0.203	-0.099	-0.365	-0.118				#N/A
WI-18	1849056.4	415548.7	-0.103	-0.112	-0.023	-0.221	-0.046	-0.109	-0.104	-0.439	-0.532
WI-19	1848905.3	415883.3	-0.062	-0.082	0.003	-0.161	-0.017	-0.095	-0.053	-0.261	-0.252
WI-21	1848381.7	416741.7	-0.087	-0.138	-0.003	-0.199	-0.101	-0.160	-0.052	-0.228	-0.044
WI-22	1848239.0	417159.6	-0.133	-0.238	-0.048	-0.329	-0.145	-0.162	-0.126	-0.299	-0.140
WI-23	1847846.7	417489.5	-0.133	-0.261	-0.062	-0.297	-0.131	-0.148	-0.125	-0.296	-0.152

PT. #	East (ft)	North (ft)	SUBSIDENCE RATE (ft/yr) FEB 91 ANNUAL RATE	FEB 92 ANNUAL RATE	DEC 92 ANNUAL RATE	MAR 94 ANNUAL RATE	FEB 95 ANNUAL RATE	JAN 96 ANNUAL RATE	DEC 96 ANNUAL RATE	Sep-98 ANNUAL RATE	Dec-98 ANNUAL RATE
WI-24	1847635.7	417920.8	-0.094	-0.209	-0.124	-0.131	-0.100	-0.121	-0.077	-0.229	-0.112
WI-25	1847452.8	418271.7	-0.048	-0.140	-0.077	-0.038	-0.057	-0.109	0.014	-0.151	0.008
WI-26	1847160.2	418779.8	-0.002	-0.086	-0.033	0.090	-0.021	-0.039	0.045	-0.088	0.116
WI-27	1847016.7	419233.8	0.011	-0.080	-0.023	0.094	-0.001	-0.025	0.050	-0.072	0.092
WI-28	1846825.7	419713.6	-0.301	0.245	-0.002	0.061	0.003	-0.028	0.061	-0.070	0.068
WI-29	1846609.0	420178.7	0.018	-0.063	-0.026	0.095	0.011	-0.026	0.055	-0.066	0.116
WI-30	1852177.9	419450.1	0.014	-0.013	0.018	-0.026	0.013	-0.003	-0.002	0.001	0.020
WI-31	1851788.1	418777.5	0.017	-0.012			0.013	0.000	0.010		0.020
WI-32	1852120.3	418762.6	0.018	-0.004			0.015	0.008	0.007	-0.008	0.008
WI-33	1851914.1	418762.6	0.016	-0.011	0.023	-0.042	0.022	-0.009	0.014		-0.084
WI-34	1851764.8	418033.6	0.023	-0.011	0.016	-0.035	0.028	-0.004	0.019	-0.018	0.020
WI-35	1851599.9	417590.3	0.017	-0.013	0.026	-0.041	0.023	-0.003	0.006	-0.008	0.040
WI-36	1851391.7	417190.4	0.011	-0.017	0.019	-0.035	0.022	-0.006	0.008	-0.016	0.020
WI-37	1851144.2	416792.0	0.004	-0.028	0.019	-0.060	0.015	-0.011	-0.021	-0.040	-0.012
WI-38	1850893.5	416374.2	-0.021	-0.056			-0.006	-0.028	-0.047	-0.169	-0.216
WI-39	1850074.9	415690.6	-0.085	-0.116	-0.023	-0.230	-0.046	-0.090	-0.119	-0.467	-0.536
WI-40	1849796.3	415222.7	-0.157	-0.171	-0.068	-0.329	-0.084	-0.149	-0.224	-0.784	-0.980
WI-41	1848925.0	414245.9	-0.090	-0.064	-0.003	-0.151	-0.030	-0.053	-0.056	-0.366	-0.444
WI-42	1848671.7	413755.3	-0.008	-0.061	0.051	-0.064	-0.004	0.008	0.023	-0.058	-0.032
WI-43	1848347.9	413267.9	-0.006	-0.052	0.028	-0.020	0.013	0.005	0.031	-0.032	-0.052
WI-44	1847704.6	413254.1	-0.007	-0.053	0.010	-0.006	0.021	-0.011	0.039	-0.035	0.040
WI-45	1847251.6	413106.1	-0.012	-0.046	0.003	0.008	-0.140	0.151	0.043	-0.036	0.064
WI-46	1846794.4	413015.5	-0.004	-0.056	0.004	0.009	0.016	-0.005	0.038	-0.031	0.080
WI-47	1850022.1	413663.8	-0.058	-0.046	0.017	-0.068	-0.025	-0.028	0.000	-0.168	-0.212
WI-48	1851344.6	418614.1	0.008	-0.058	0.050	-0.036	0.009	-0.009		-0.041	0.012
WI-49	1850868.8	418408.7	-0.006	-0.075	-0.036	0.075	-0.002	-0.017		-0.062	0.068
WI-50	1850502.3	418213.5	-0.060	-0.102	-0.017	-0.011	-0.019	-0.045		-0.093	-0.016
WI-51	1850028.2	418007.0	-0.109	-0.143	0.008	-0.131	-0.054	-0.094		-0.125	-0.040
WI-52	1849565.8	417792.9	-0.131	-0.175	-0.018	-0.202	-0.133	-0.137		-0.168	-0.068
WI-53	1849129.3	417577.9	-0.134	-0.196	-0.029	-0.332	-0.169	-0.158	-0.083	-0.224	-0.100
WI-54	1848672.4	417382.4	-0.132	-0.218	-0.055	-0.380	-0.159	-0.164	-0.105	-0.290	-0.136
WI-55	1847965.5	416923.2	-0.139	-0.210	-0.074	-0.173	-0.122	-0.146	-0.111	-0.269	-0.272
WI-56	1846900.0	416512.4	-0.104	-0.135	-0.058	-0.017	-0.047	-0.053	-0.016	-0.148	-0.312
WI-57	1846251.6	416197.3	-0.033	-0.054	-0.034	0.064	-0.038	-0.006	0.045	-0.072	-0.244
WI-58	1845505.9	415724.3	-0.019	-0.038	-0.020	0.090	-0.038	0.003	0.006	-0.022	-0.036
WI-59	1848054.3	415253.1	-0.032	-0.061	-0.048	-0.014	0.003	-0.048	-0.032	-0.220	-0.164
WI-60	1848234.4	414369.8	-0.028	-0.090	0.015	0.053	-0.078	-0.061	-0.025		ng
WI-61	1849809.2	414883.7	-0.190	-0.208	-0.077	-0.392	-0.121	-0.172	-0.291	-1.048	-1.264
WI-62	1851261.4	415860.5	-0.007	-0.034	0.008	-0.072	-0.005	-0.007	-0.058	-0.112	-0.132
WI-63	1848539.4	414432.3	-0.059	-0.136	0.011	-0.011	-0.104	-0.056	-0.051	-0.394	-0.276
WI-64	1848767.5	414374.5	-0.072	-0.164	0.028	-0.169	-0.036	-0.072	-0.073	-0.436	-0.556
WI-65	1849051.5	414232.0	-0.098	-0.070	-0.006	-0.165	-0.028	-0.092	-0.028	-0.396	-0.460
WI-66	1849090.2	414124.5	-0.081	-0.054	0.003	-0.130	-0.009	-0.073	-0.009	-0.284	-0.332
WI-67	1849149.6	414042.2			0.000	-0.129	-0.008	-0.072	-0.018	-0.279	-0.344
WI-68	1849164.0	413862.0	-0.084	-0.060	-0.013	-0.134	-0.023	-0.062	-0.027		0.000
WI-69	1849235.9	413772.4	-0.046	-0.021	0.014	-0.064	0.008	-0.032	0.021	-0.105	-0.140

			SUBSIDENCE RATE (ft/yr)								
			FEB 91	FEB 92	DEC 92	MAR 94	FEB 95	JAN 96	DEC 96	Sep-98	Dec-98
			ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL	ANNUAL
PT. #	East (ft)	North (ft)	RATE	RATE	RATE	RATE	RATE	RATE	RATE	RATE	RATE
WI-70	1849239.0	413657.3	-0.044	-0.016	0.011	-0.057	0.016	-0.028		-0.077	#N/A
WI-71	1849278.5	413530.1	-0.042	-0.013	0.017	-0.048	0.013	-0.023	0.038	-0.046	-0.096
WI-72	1849392.7	413134.1	-0.032	-0.006	-0.021	0.021	0.024	-0.015	0.050	-0.040	-0.068
WI-73	1849487.8	412823.8	-0.031	-0.008	0.022	-0.047	0.025	-0.021	0.057	-0.039	-0.092
WI-74	1850016.4	412512.8	-0.028	-0.014	0.021	-0.044	0.014	-0.016	0.059	-0.038	-0.116
WI-75	1850529.5	412341.9	-0.025	-0.011	0.015	-0.036	0.006	-0.010	0.060	-0.034	-0.140
WI-76	1851013.1	412184.8	-0.027	-0.012	0.021	-0.029	-0.003	-0.017	0.056	-0.035	-0.076
WI-77	1851507.7	412063.2	-0.027	-0.008	0.018	-0.011	-0.014	-0.015	0.061	-0.036	-0.052
WI-78	1851982.1	412173.9	-0.025	-0.008	0.018	-0.016	-0.011	-0.015	0.056	-0.032	-0.044
WI-79	1852463.8	412242.8	-0.024	-0.013	0.018	-0.014	-0.010	-0.015	0.052	-0.026	-0.072
WI-80	1852970.4	412348.6	-0.026	-0.016	0.022	-0.014	-0.006	-0.020	0.041	-0.029	-0.036
WI-81	1853477.0	412454.0	-0.025	-0.010	0.004	0.008	-0.005	-0.018	0.043	-0.123	-0.024
WI-82	1853930.1	412545.1	-0.020	-0.009	0.012	-0.014	0.006	-0.016	0.026	0.014	0.616
WI-2 DEEP	1853202.3	418186.8	0.044	-0.007	0.006	0.023	0.007	0.016	0.037	0.014	-0.180
WI-3 DEEP	1852529.5	416870.1	0.054	-0.009	0.021	-0.015	0.019	-0.010	0.016		-0.140
WI-17 DEEP	1849479.0	414734.7	-0.170	-0.209	-0.095	-0.363	-0.271			-0.251	#N/A
WI-19 DEEP					-0.005	-0.164	-0.024	-0.084		-0.016	-0.320
WI-36 DEEP					0.017	-0.031	0.016	-0.003		-0.173	0.028
WI-47 DEEP	1850029.4	413652.4	-0.056	-0.043	0.013	-0.069	-0.019	-0.028		-0.247	-0.224
WI-59 DEEP	1848049.9	415275.0	-0.033	-0.062	-0.048	-0.015	0.006	-0.050		-0.079	-0.172
WI-60 DEEP	1848223.9	414365.4	-0.025	-0.081	0.008	0.057	-0.076	-0.056		-0.103	-0.068
MORTON 1							-0.065	-0.065	-0.044	-0.156	-0.100
MORTON 2							-0.076	-0.076	-0.065	-0.084	-0.048
COGO A	1847520.1	415356.5					-0.065	-0.055	-0.029	-0.080	-0.096
COGO C	1847451.5	415270.8					-0.065	-0.055	-0.018	-0.065	-0.116
COGO D	1847521.2	415847.2					-0.087	-0.087	-0.063	-0.134	-0.052
COGO 11	1847450.0	415972.2						-0.076	-0.097		not located
COGO 12	1847816.3	417444.2					not located	not located	not located	not located	ng
COGO 13	1847246.9	415502.2							-0.039	-0.080	-0.072
COE 924	1845390.1	416246.8								-0.023	-0.068
COE 923	1845541.3	415469.8							-0.646	0.408	-0.120

Appendix 3

memo: S. J. Bauer to R. Myers dated 2/24/98

"Implications of Recent Subsidence Measurements at Weeks Island – CORRECTED"

Sandia National Laboratories

Albuquerque, New Mexico 87185-0706

date: February 24, 1998

to: R. Myers DOE SPR PMO FE 4422

from: S. J. Bauer 6113, MS0706

subject: Implications of Recent Subsidence Measurements at Weeks Island - CORRECTED

Elevation measurements have been taken at Weeks Island since May of 1983 to facilitate our understanding of subsidence around the SPR site. These measurements have been made annually and have been tied to a benchmark off the island. It was decided to supplement this annual data with quarterly elevation measurements during the year that included the oil withdrawal and subsequent brine refill. These quarterly measurements (conducted 3/97, 7/97 and 9/97) are in the immediate vicinity of Sinkhole #1, a site of historic localized subsidence. It was thought that these measurements would help identify potential localized effects in this vicinity.

The monuments (Figure 1) surveyed in the quarterly measurements include WI-68 through WI-73 which trend north northwest from the railroad track and are located west and south of Sinkhole #1, WI-47 deep southwest of Sinkhole #1, and WI-12 through 16 which follow the road from east to west, passing Sinkhole #1. Monument WI-15 is physically closest to Sinkhole #1.

The quarterly measurements are not tied to the benchmark off the island. These measurements have been analyzed by comparing them to monument WI-73. Monument WI-73 is about 1300 feet from and south-southwest of the sinkhole; it is also about the same distance from the mine boundary. Therefore WI-73 should not be effected dramatically by mine related subsidence.

The vertical displacement for each station relative to WI-73 versus time is plotted in Figure 2 beginning in 2/90. All data presented in Figure 2 are derived by subtracting the elevation change for Monument WI-73 from that observed at a given station. The last 3 measurements plotted constitute the recent data collected for this report (3/97, 7/97, and 9/97). Data plotted begins in 2/91 and runs until 9/97. The data trend indicates a slight increase in the downward displacement rate since 1/96. While it appears that the subsidence rates have been greatest for monuments in the immediate vicinity of the sinkhole, the rates appear to be historically uniform.

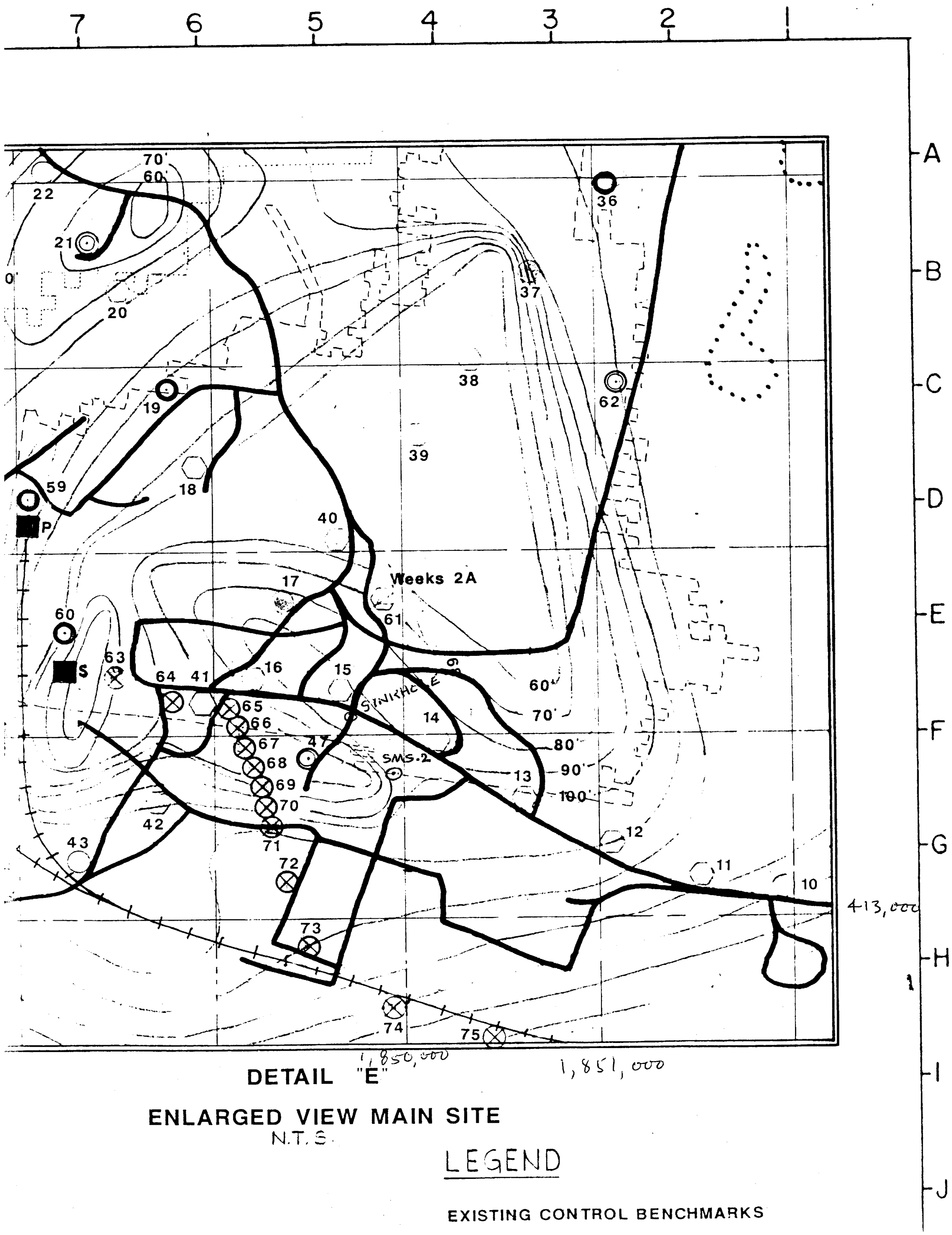

Figure 1. Location map for monuments.

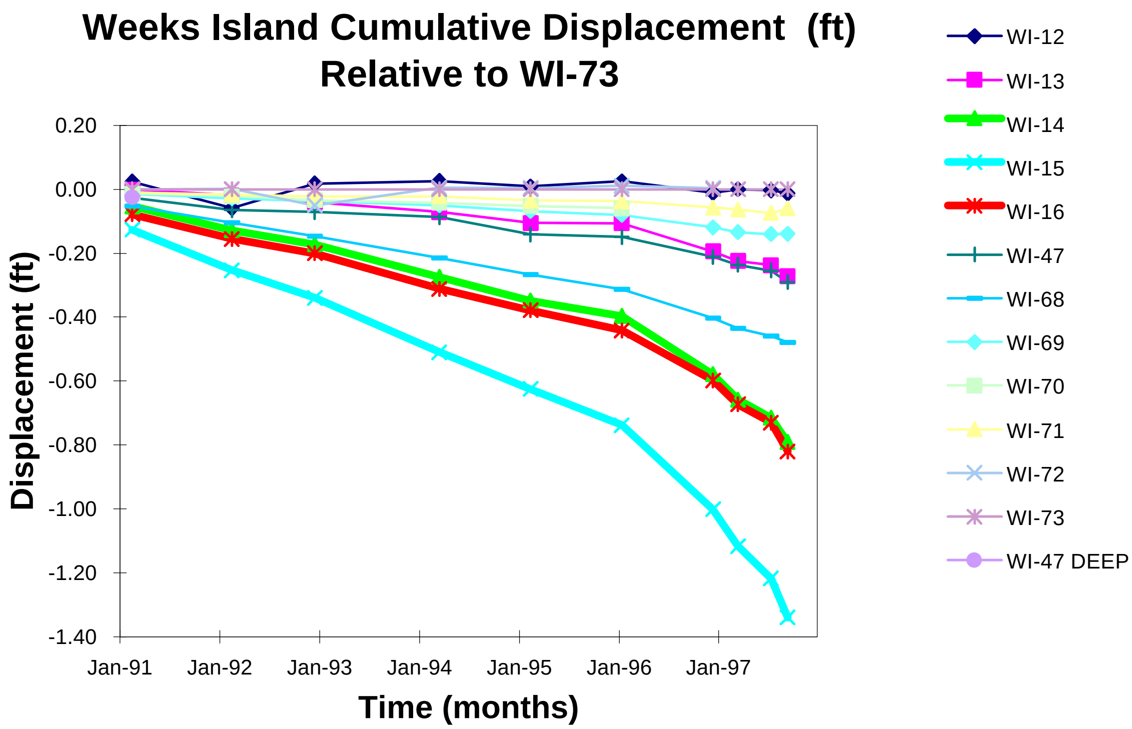

Figure 2. Weeks Island cumulative displacement (ft) relative to monument WI-73.

Figure 3 presents subsidence displacements considered relative to the benchmark off the site through 12/96. This presentation is made to provide a comparison with the WI-73 method. The differences observed are small, except that the downward trend in the data after 1/96 is less for the "fixed" benchmark data set. This implies that using the WI-73 method has some validity, however it is unclear if the magnitudes in downward displacement are really as great as indicated in Figure 2; this could be an artifact of the analysis method. The recent measurements will be reassessed with the next fixed benchmark study scheduled for this spring.

In Figure 2 the subsidence rate for WI-15 is consistently greater than the others measured beginning in 2/91. Although WI-15 is closest to the sinkhole, its movement may be due primarily to its position relative to the mine center.

There is a slight increase in subsidence rate after the 1/96 measurement. This is consistent with the timing for oil withdrawal.

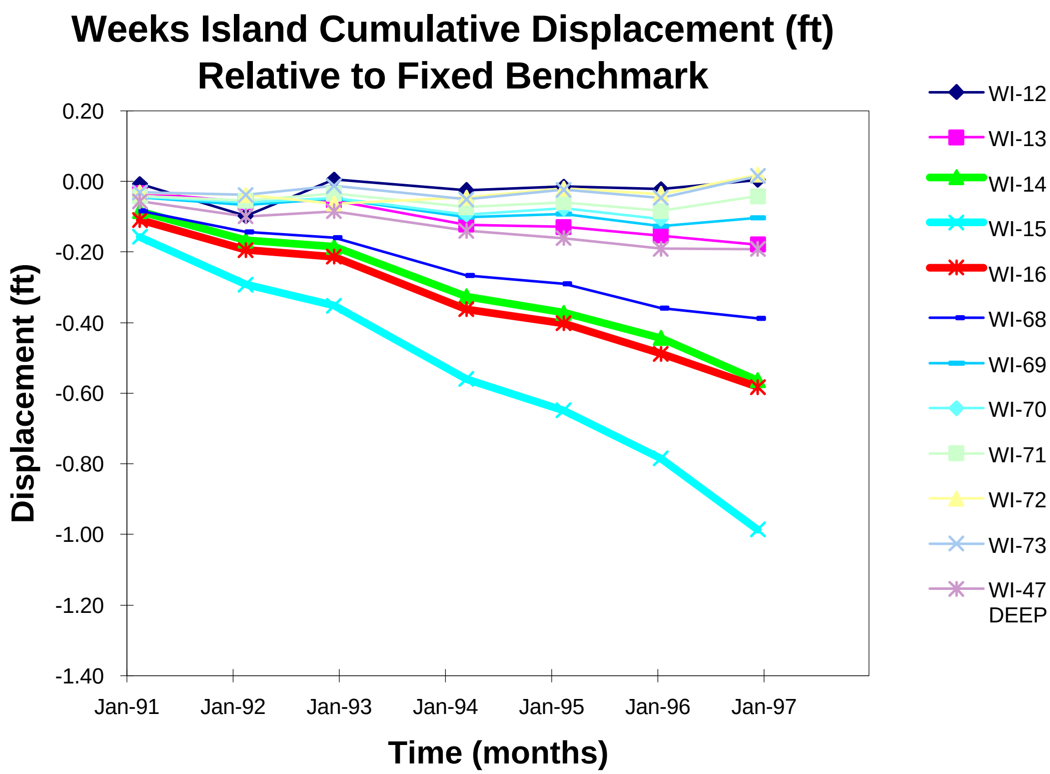

Figure 3. Weeks Island cumulative displacement (ft) relative to fixed benchmark for all monuments included in this study.

In Figure 4, WI-14, 15, 16 (already discussed) are presented as well as WI- 39 and WI-40. The comparison is made to demonstrate that WI-14, 15, and 16 data are consistent in magnitude with historical data elsewhere over the mine.

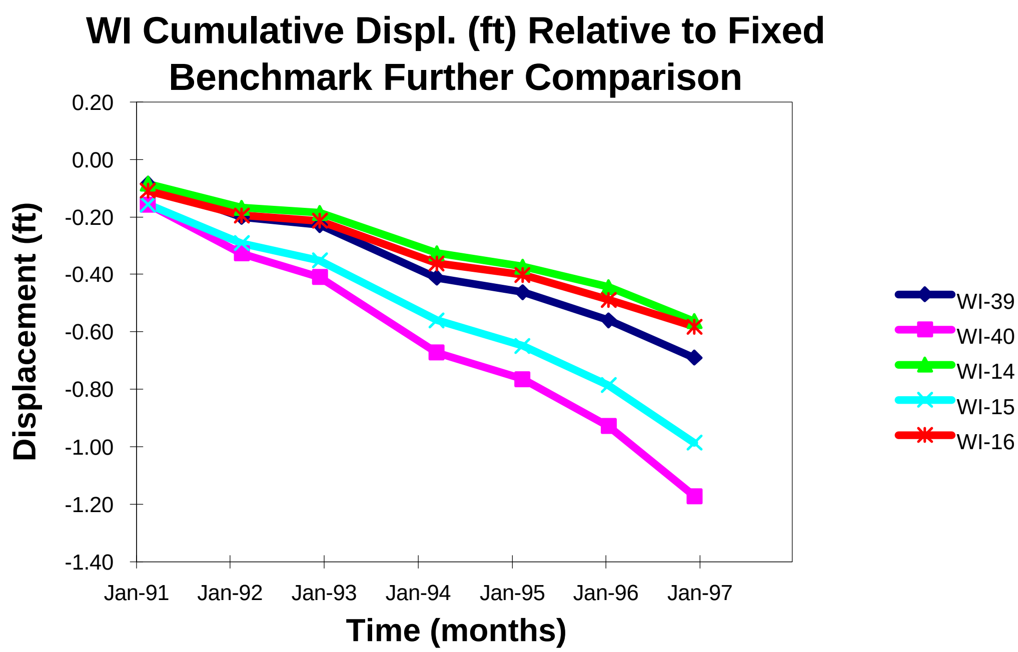

Figure 4. Weeks Island cumulative displacement (ft) relative to fixed benchmark for selected monuments included in this study as well as other monuments for comparison.

We conclude that subsidence near the sinkhole is consistent with observed subsidence over other areas of the mine.

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N. Shourbagi	DOE SPR PMO FE 4421
J. Barrington	DM EF 21
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R. Lynch	6100 MS 0701
J. Linn	6113 MS 0706
Staff	6113 MS 0706

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